FUEL-CELL POWERED VEHICLES

Are fuel cells the technology that will allow us to replace the polluting internal-combustion engine with a cleaner, good-performing alternative?

BILL SIURU

It is hard to beat the internal-combustion engine (ICE) when it comes to performance, range, cost, safety, reliability, and user-friendliness. After all, it has been "under development" for over a century. However, there are several compelling reasons to replace the ICE with a different technology.

For one, there is the matter of petroleum resources. The U.S. now imports nearly half of all petroleum consumed by cars and light trucks. That will increase as the number of vehicles and miles driven continues to increase.

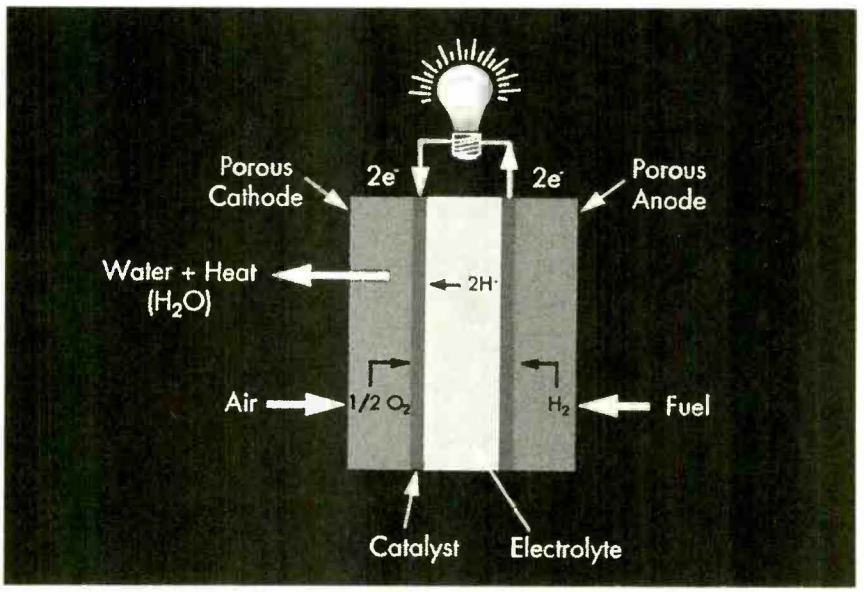
Also, many scientists postulate that global warming results from greenhouse gases, which are produced when fossil fuels are combusted. As such, one of the most significant source of greenhouse gases is the automobile.

Is it possible to reduce those problems by further refining the ICE? Perhaps, but likely not enough to do more than delay the day of reckoning somewhat. Even with the most sophisticated electronic fuel-injection systems and the use of alternative fuels like natural gas, methanol, and ethanol, the ICE cannot meet the zero-emission-vehicle (ZEV) mandates already legislated in California, New York, and Massachusetts and under serious consideration in other states and Canadian provinces.

So, other than banning the automobile, what are the alternatives? The technology most see as the best alternative to the ICE is the battery-powered electric vehicle. However, at the present, the limits that that technology places on the user in terms of range, performance, cost, and flexibility likely means that the battery-powered car will never replace the ICE except in narrow niche markets such as for urban transport and as neighborhood electric vehicles (See "Neighborhood Electric Vehicles" in the January 1998 issue of **Electronics Now** for more on that).

But there is another technology that is getting serious consideration—the fuel cell.

Why Fuel Cells? Hydrogen is the ultimate clean fuel. When combined with air to produce energy, only heat, water, and a small amount of oxides of nitrogen (NOx)



How a fuel cell works. Each membrane assembly consists of electrodes (anode and cathode) with a thin layer of catalyst, bonded to either side of a proton-exchange membrane (PEM). Air flows through the channels in flow-field plates to the cathode. Oxygen in the air attracts the hydrogen protons through the proton-exchange membrane. The air stream also removes the water created as a by-product of the electrochemical process. (Ballard)

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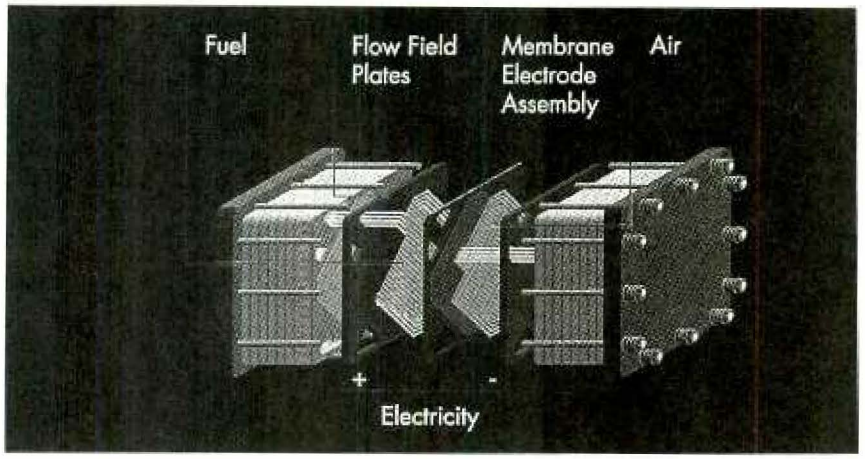
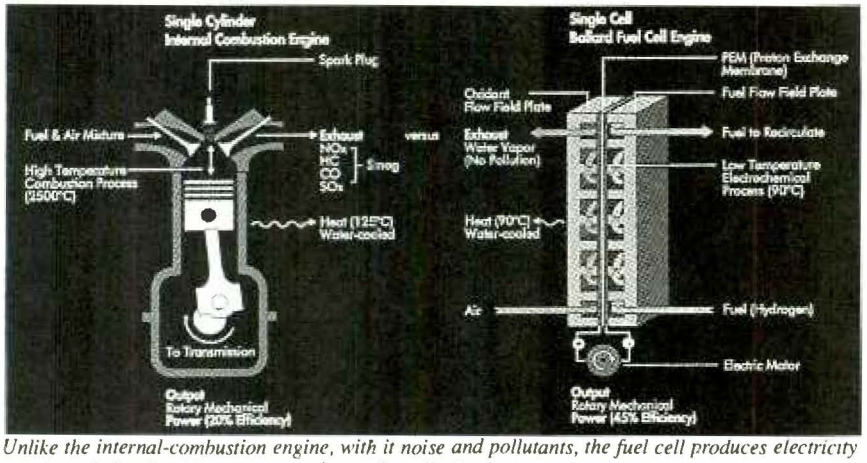


Stacking together more PEM cells increases the voltage, while increasing the surface area of the cells increases the current. (Ballard)



Unlike the internal-combustion engine, with it noise and pollutants, the fuel cell produces electricity quietly and cleanly with water as the by-product. (Ballard)

are produced as by-products. There are no greenhouse gases. Some say the 21st Century will be the "Hydrogen Century" as hydrogen replaces fossil fuels. Hydrogen is extremely abundant, indeed the most abundant element in nature, and is a renewable resource. It is available worldwide since it can be produced from many sources from natural gas to bio-mass including agriculture crops and landfill waste. Using electrolysis, hydrogen can be produced from water anywhere that electricity from any source—including "clean" ones such as wind, solar, or hydro power—is available.

All that sets the stage for the current intensive interest in fuel cells for automotive applications. Though the fuel cell was conceived in 1839 by Sir William Grove, it did not really see practical use until the space age when hydrogen-oxygen fuel cells supplied power onboard the Gemini, Apollo and Skylab spacecraft. They are currently used on the Space Shuttle.

How A Fuel Cell Works. Like a battery, a fuel cell is an electrochemical device that directly produces DC electricity without combustion and without producing polluting emissions. Like batteries, fuel cells have anodes, cathodes, an electrolyte, and positive and negative terminals. Unlike batteries, they do not have to be recharged. Fuel cells produce electric power as long as they are supplied with fuel (namely hydrogen) and oxygen or air.

Companies like Ballard Power Systems, International Fuel Cells, Plug Power, Mechanical Technology, Inc. and others are working on fuel cells for automotive applications. For instance, Ballard, located in Vancouver, British Columbia, has developed several versions of its Proton Exchange Membrane (PEM) fuel cells that have been installed in prototype cars and buses.

The PEM fuel cell consists of two electrodes (anode and cathode) separated by a polymer-membrane electrolyte. Each electrode is coated on one side with a thin layer of platinum catalyst. That catalyst causes the hydrogen fuel to separate into free electrons and protons (positive hydrogen ions) at the anode. The free electrons are conducted as usable electric current, passing through the external circuit. Like with battery-powered EVs, electrical energy from the fuel cell is supplied to an electric motor, or motors, to propel the vehicle. The protons migrate through the membrane electrolyte to the cathode, where they combine with oxygen from the air and electrons from the external circuit to form water and heat. The heat could be used for passenger comfort, windshield defrosting, etc. The output voltage of the fuel cell is increased by stacking individual cells in series; increasing the surface area of the cells increases the current produced.

Storing or Making Hydrogen On Board? Two quite different approaches are being considered with respect to the hydrogen fuel. The nearer term approach is to convert conventional fuels like gasoline, methanol, or ethanol into hydrogen on board the vehicle. The advantage of that technique is that the current infrastructure for transporting and distributing fuels would need little or no change and motorists would see little difference when they refuel.

The longer term approach is to store hydrogen on board as a compressed gas, cryogenic liquid, or in a hybrid material. On-board storage results in a simplified system with higher overall efficiency compared to on-board fuel processing. The disadvantage is that on-board storage requires a completely revamped transportation and distribution infrastructure to handle hydrogen. That could take years to put into place.

An example of a system to produce hydrogen on board is the reformer developed by the Argonne National Laboratory for producing hydrogen from methanol. In the Argonne reformer, a noz-

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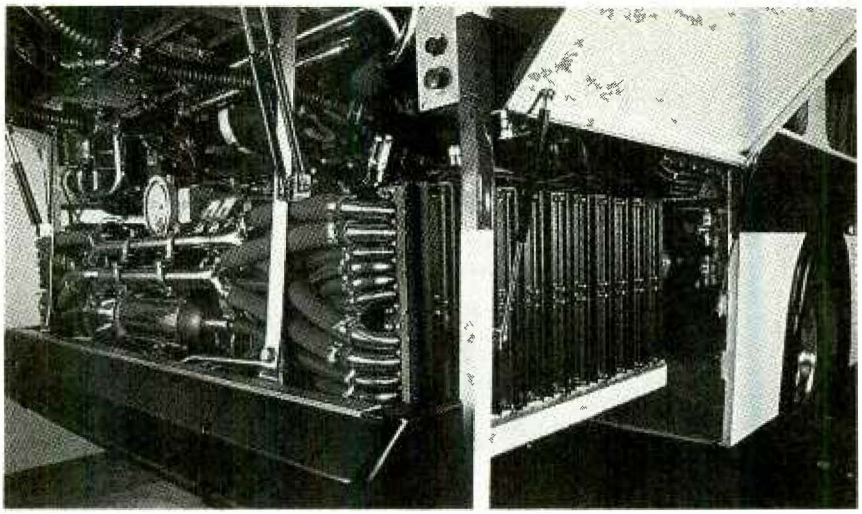
zle sprays liquid methanol into a cylinder and an ignition source starts the chemical process that combines methanol with oxygen from the air to release a hydrogen-rich mixture of gases. That hydrogen-rich gas mixture is injected into the fuel cell. Since the reformer produces both carbon dioxide and carbon monoxide, a small on-board chemical reactor converts the carbon monoxide into carbon dioxide.

Consisting basically of a cylinder packed with a common, inexpensive catalyst, the design is quite simple and would be inexpensive to manufacture. The device is small enough—it takes up less volume than a seven gallon container—to fit under the hood of a compact car. While not as efficient as an on-board hydrogen-storage system, the reformer/fuel cell system could be more efficient than an ICE, yet it produces negligible emissions besides carbon dioxide.

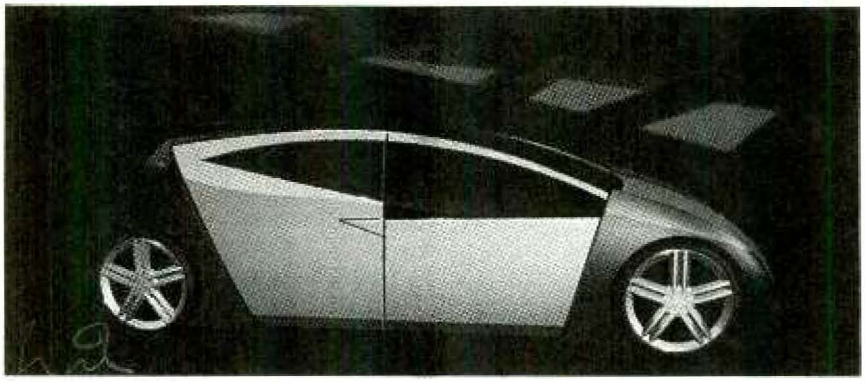
Recently, Plug Power LLC, the Arthur D. Little Research Foundation, and the Los Alamos National Laboratory have successfully developed a gasoline-to-hydrogen reformer. That represents a breakthrough in that it overcomes the problem of fuel-cell poisoning from the high levels of carbon dioxide produced when gasoline is reformed. That is why methanol is being used in other reformer developments.

Unfortunately, largely because of the Hindenburg disaster, extremely explosive hydrogen has a negative image to many people. The hydrogen-filled Zeppelin exploded over Lakehurst, NJ in 1937, killing 36 people. Thus, it could still be a hard sell to convince the public that hydrogen stored as a compressed gas or a cryogenic liquid is safe on the highway. Liquid hydrogen means storage at cryogenic temperatures, which is both complex and expensive. Current compressed gas and liquid hydrogen-storage techniques are heavy and bulky so they greatly limit the range of the vehicle—the same problem that faces battery-powered EVs.

Another solution is to use a metal-hydride storage system. Here, cold hydrogen is absorbed in the hydride material. When heated, the material releases gaseous hydrogen that could be used in a fuel cell. That storage technique is considered safer than either compressed gas or cryogenic storage because the metal hydride releases hydrogen slowly and at relatively low pressure. One drawback is that the storage equipment is still quite heavy and bulky. Therefore, it is most appropriate for use in large vehicles such as buses.



The 275-horsepower Ballard fuel-cell engine fits into the same space as a diesel bus engine. (Ballard)



Ford's radically designed P2000 could be powered by a fuel-cell engine. (Ford)

Buses First. While it may be a while before fuel-celled passenger cars and light trucks are on the road, fuel-cell buses are already here, at least in demonstration programs under real-world conditions. Buses have the space and can carry the additional weight of fuel cells using today's technology. Also urban mass-transit agencies are interested in reducing emissions either voluntarily or in many cases, to meet government mandates for clean air. According to the California Air Resources Board, a heavy-duty diesel bus generates 11.8 tons of NOx over a 12-year life span. Even so-called clean buses operating on natural gas will emit 5.6 tons of NOx. A fuel cell bus can be designed to emit no NOx.

Ballard Power Systems chose transit buses as the first transportation application for its fuel cells. Ballard's, and the world's, first fuel-cell-powered transit bus went on the road in 1993. It was a 32-foot transit bus with a 125-horsepower Ballard PEM fuel-cell engine fueled directly by hydrogen.

In 1995, Ballard introduced its second bus, a 40-foot ZEV with a 275-horsepower Ballard fuel-cell engine. It has a range of 250 miles before refueling and matches the performance of a diesel transit bus, but without the noxious fumes; and it produces far less noise. The only emission from the tailpipe is warm, moist air.

This year, the Chicago Transit

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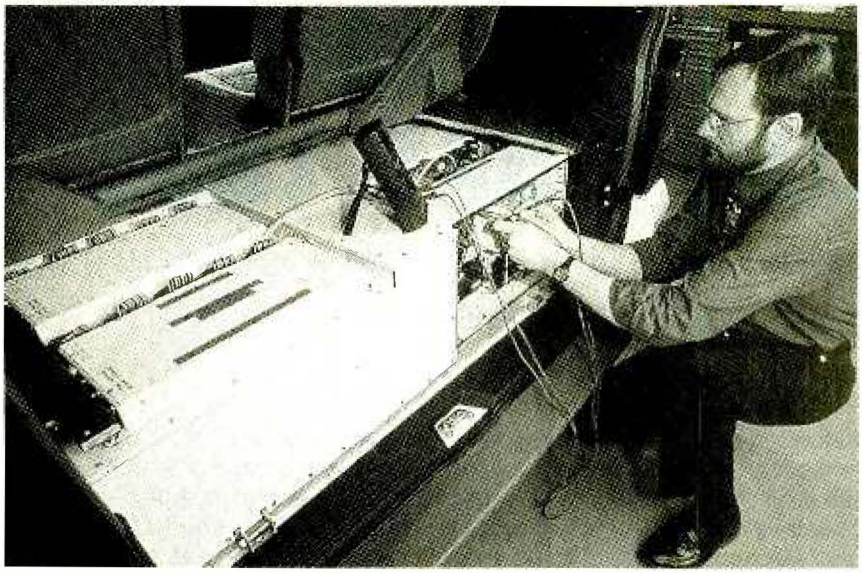

The Ballard fuel cells fit under the backseat of the NECAR II minivan and do not reduce the seating or luggage capacity of the vehicle. (Ballard)

FOR MORE INFORMATION

Ballard Power Systems Inc.
9000 Glenlyon Parkway
Burnaby, BC Canada V5J 5J9
Web: www.ballard.com

Chrysler Corporation/Fuel Cell Program
30900 Stephenson Highway
Madison Heights, MI 48071
Tel: 810-583-5270; 810-583-5234

Energy Partners
1501 Northpoint Parkway, Suite 102
West Palm Beach, FL 33407
Tel: 561-688-0500
Fax: 561-688-9610

Ford Motor Company/Alternative Power Source Technical Department
PO Box 2053
Dearborn, MI 48121-2053
Tel: 313-594-7957
Fax: 313-845-4495

Fuel Cells 2000
1625 K Street NW, #790
Washington, DC 20006
Tel: 202-785-9620
Fax: 202-785-9629
Web: www.fuelcells.org

General Motors/AC Rochester
PO Box 20366
Rochester, NY 14602
Tel: 716-359-6423
Fax: 716-359-6015

International Fuel Cells
PO Box 739
195 Governors Highway
South Windsor, CT 06074
Tel: 860-727-2310
Fax: 860-727-2399

Mercedes-Benz of North America
One Mercedes Drive
Montvale, NJ 07645-0350

Authority and BC (British Columbia) Transit will each take delivery of three commercial prototype fuel-cell buses. The buses will undergo a two year test program that will provide the necessary performance, cost, and reliability data for commercialization of the final product.

Fuel-Cell Cars. Many automakers have fuel-cell R&D programs. Ford, General Motors, and Chrysler are conducting fuel-cell development as part of the Partnership for a New Generation of Vehicles (PNGV)—a partnership between the Federal government and the automakers' U.S. Council for Automotive Research (USCAR) coalition.

Ford is developing a full-performance direct-hydrogen PEM system as part of its P2000 project. "Direct" means that hydrogen fuel is stored onboard the vehicle. The P2000 project is aimed at producing a medium-sized family sedan that weighs only 2000 pounds, or about 1200 pounds less than a Ford Taurus, while being about three times as fuel efficient. Ford is working with International Fuel Cells, and Mechanical Technology, Inc. in this Department of Energy project. Ford recently announced it had demonstrated a 50 kW, automobile-size PEM fuel-cell engine. The system weighs 300 pounds and takes up approximately nine cubic feet, so it could easily fit under a car hood.

Chrysler's Pentastar program is working with Allied Signal on a Design-to-Cost Direct Hydrogen PEM system. Chrysler hopes to have a prototype gasoline-to-hydrogen fuel cell vehicle on the road by 1999. General Motors' Delphi Divisions plus Ballard and DuPont are working on a 30-kW methanol PEM system.

Daimler-Benz recently unveiled the NECAR 3, the third in a series of fuel-cell-powered "New Electric CARs." Over the past couple of years, Daimler-Benz has also developed the NECAR 1, NECAR 2, and NEBUS transit bus. All used Ballard fuel cells. Indeed, Daimler-Benz has acquired a 25% share in Ballard.

Unlike the previous three D-B fuel-cell vehicles, where the hydrogen was stored in heavy and bulky pressurized tanks, the NECAR 3's fuel is stored in rather ordinary fuel tanks. That is because the fuel is methanol. According to Daimler-Benz, methanol was chosen over gasoline and diesel because of its higher efficiency and lower emissions. However, the engineers are considering a multi-fuel system on early-generation fuel-cell-powered vehicles to allow for a phase-in period until methanol is readily available everywhere.

The NECAR 3's methanol reformer uses a water-vapor technique to convert methanol to gaseous hydrogen. Methanol and water vaporize at about 280 degrees C in the reformer to produce hydrogen plus carbon dioxide and carbon monoxide. Following catalytic oxidation of CO, the purified hydrogen is delivered to the fuel cell.

As a demonstration of the practicality of its new reformer and fuel-cell technology, the NECAR 3 uses a new Mercedes-Benz A-Class subcompact, a 12-foot long four-door sedan. The compact reformer, which is only about 18-inches tall, is located behind the rear seat along with the methanol tank and control system. The A-Class's innovative double floor sandwich construction allows the fuel cells and auxiliary units to be installed completely under the passenger compartment. The 11-gallon fuel tank holds suffi-

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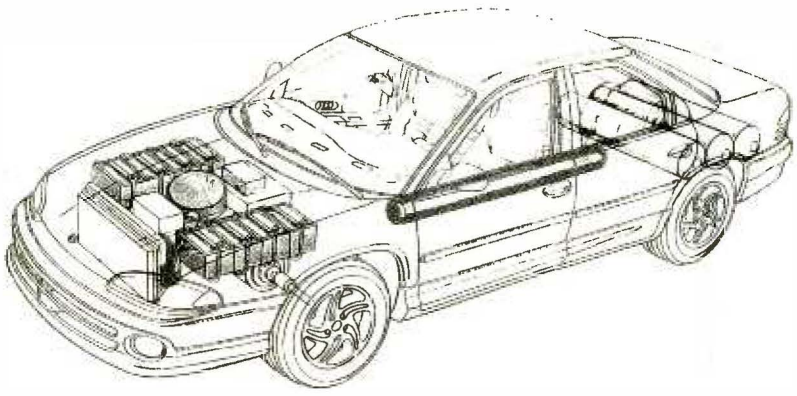
cient fuel for a very respectable 250-mile range. Mercedes-Benz has said it plans to produce 100,000 fuel-cell powered A-Class cars by 2005.

Not only smaller and more efficient, the new reformer process gives improved performance and dynamic response. According to Mercedes-Benz, when you press the throttle, 90% percent of the power is available in two seconds. That puts fuel-cell vehicles on a par with conventional gasoline- or diesel-powered automobiles. The NECAR 3 is virtually emission-free. Neither nitrogen oxides nor soot particles are produced during the reformulation process or in the fuel cell itself.

In Japan, Mazda has demonstrated a 20-kW PEM fuel-cell engine and Toyota unveiled its first fuel-cell vehicle with a 20-kW PEM system in 1996 with a second-generation version planned for this year. Honda is also working on a fuel-cell vehicle. Renault, in collaboration with Volvo, is working on its FEVER (Fuel Cell Vehicle of Extended Range). Reportedly, BMW, Nissan, Volkswagen, Siemens, Toshiba, and others have fuel-cell projects on the drawing board.



Hydrogen would be stored on-board in the Chrysler-Pentastar direct-hydrogen PEM Fuel-Cell Program vehicle. The PEM fuel-cell system would replace the internal combustion engine. (Fuel Cells 2000)

Will you see a fuel-cell car down at your local dealer soon, or even within a few years? Probably not. Besides bugs still to be worked out, there is the matter of cost. Fuel cells are still many times more expensive than the most sophisticated and powerful dual-overhead camshaft, 48-valve V-12 running on ordinary gasoline. Also, automakers are understandably reluctant to cast aside their huge investment in the internal-combustion engine for a new technology that would require another huge investment for new manufacturing facilities and whose consumer acceptance is still an unknown quantity. Still, fuel-cell technology might just represent the best current option to replace the internal-combustion engine. Ω

NATIONAL TECHNICIAN'S DAY

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To qualify for Journeyman certification, a technician must have four years or more of education and/or experience in electronics. He or she must also have passed the Associate CET exam and must take and pass a 75-question Journeyman Option exam on one of several areas of specialization. Those areas include: Audio, Biomedical, Communications, Computers, Consumer Products, Industrial, Radar, Video, and Appliance Servicing. A technician may also use the Associate certification issued by the Electronics Technicians Association International (ETA) to qualify for any of the Journeyman options.

If you have already attained Journeyman certification, you can take one of several 25-question Endorsement exams designed to prove advanced expertise in a specific field. Currently, Endorsement exams are available in Camera/Camcorder/8mm, Computer Monitor, Motor Control, VCR, Audio, CD/VLD, and Digital Communications.

The fee structure is as follows: For the Associate exam, the fee is $30. For any Journeyman Option, the fee is $35. If both the Associate and a Journeyman Option exam are taken at the same time, the fee is $50. Each test has a two-hour time limit, and a score of 75% or better is required to pass. For the Journeyman Endorsement exam, the fee is $35, there is a one-hour time limit, and a 75% score is required to pass the exam.

ISCET test examiners are also qualified to administer FCC element tests. The fees vary depending on which elements are taken.

To Commemorate T-DAY. ISCET invites all technicians to celebrate National Electronics Technicians Day during the Week of April 21 through April 25, 1998, which has been designated T-WEEK. If you are planning to take the CET exams, now is the time as during T-WEEK, ISCET's network of Certified Test Administrators will be providing opportunities for interested technicians to obtain their certification. Whether you are interested in completing your Associate, Journeyman , or Journeyman Endorsement Certificate; gaining continuing education units; or want to sit for one of many FCC elements, contact one the examiners in the Volunteer Examiners box that accompanies this article. Those test administrators are dedicated to the continued growth of the CET program and anxiously await hearing from you. For more information on the CET program, visit ISCET's home page located at www.iscet.org. Ω

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